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Precise Determination of Probable Leak Path and Associated Source Noise with The Novel Technique of "Beamforming" Using Multiple Hydrophone Arrays; A Case Study from Sanggar-06 Well Indonesia

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Abstract.
The Beamforming technique was proven to leverage noise detection with multiple - hydrophone, it was designed to process the multiple waveforms from hydrophone in the frequency domain and modeled the delay time of leak signal arrivals between the hydrophones in order to locate the accurate leak position and flow path. The purpose of this paper to show the combination of these techniques that are -provide critical information for further plans to restore well barrier condition.
Sanggar-06 well has a mechanical problem on the 5-1/2" Tubing connection after the completion program in 2004, it was detected some joints was not tightened properly as shown by Caliper Survey. Based on daily monitoring in early 2011, the tubing pressure and A-Annulus pressure at the same pressure level and indicated continuous communication both in shut-in and flowing conditions. The first noise log survey was run in May 2011 and detected 2 leak points, later the leak path was isolated with Tubing Patch by April 2012 and solved the problem.
In March 2017 the Sanggar-06 exhibited the same problem of communication between Tubing and A-Annulu.s, this was then followed up with 2nd run of the noise log. The result from this noise log run did not show a clear indication of where the leak position was located and indicated a 7-point potential leak position on the production string.
Before the decision to have a retubing program to recover the tubing integrity, the 3rd noise log was run by adding 3 hydrophones (a total 6 hydrophones) and implementing a beamforming technique to locate the leak point. The re-run was paid off with the result by that confirming a leak point at the from packer assembly.
The benefit of this work has resulted in changes of the original tubing integrity recovery plan that use work over rig to rigless activity; which have impact massive or cost saving terms of restoring the well barriers objective in the execution of this operation.

Keyword(s): noise log, beamforming, leak path, barrier

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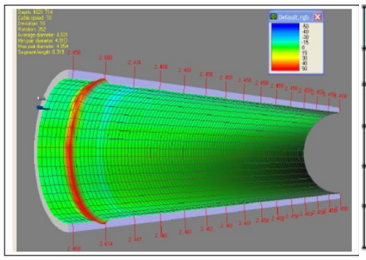
1 Introduction

The Sanggar-06 well is one of gas producer on onshore Suban field (Medco E&P Grissik (MEPG)), the fields produce natural gas and associated liquids at the Suban gas plant located in South Sumatera, Indonesia. All Suban asset wells are naturally gas flowing with rich condensate and been Producing for over 20+ years. To maintain decline rate from limited wells, one of the enhancements was re-completion program to upsize the tubing in order to reduce friction or pressure losses through the tubing.

From all the re-completion upsize tubing program, only the Sanggar-06 well that experienced communication between tubing pressure and A-Annulus pressure. Prior the program in 2004, the well used 4-1/2" tubing size and plan to be upsize to 5-1/2". During activity it was detected the torque was could not achieve the recommendation values and make some joint has some gap that lately known by run caliper survey in 2007.



Joint #	Depth (m MDDF)	Gap interval (mm)	Max Penetration (inch)
49	1714.28	9.0	0.096
2	1021.739	9.0	0.143
10	944.94	12.2	0.137
43	630.77	7.1	0.074
104	52.038	5.1	0.059

Figure 1. Caliper survey on significant gap connections.

Even though the last operation problem on re-completion did not giving direct impact to production, it will affect to the well life when gas production fill-up the A-Annulus and replacing packer fluid that was happened in early 2011. The gas confirmed occupied A-Annulus after the pressure not able to bleed-off to 0 psi, has same level with tubing pressure that indicated continuous communication both in shut-in and flowing conditions.

The 1st noise log measurement was run in May 2011 and detected 2 leak points at 944 m and 1021 m on 'figure 2' that corresponding with previous caliper result on 'figure 1'. With the noise log and temperature log verification, follow-up mitigation was taken to isolate gas production by set tubing patch on April 2012 and solved the tubing leak.

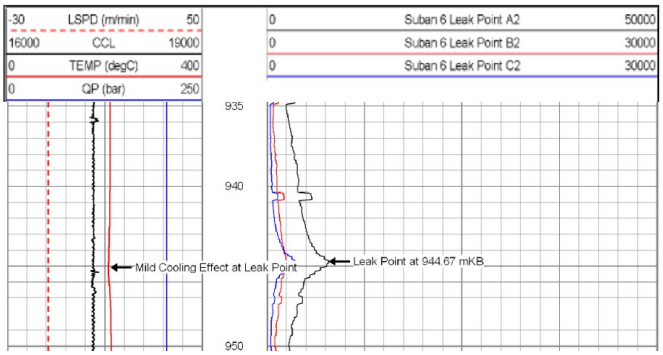


Figure 2. 1st Noise log (2011) that capture leak position on 944.67 mKB

The integrity of tubing was not survive long, the Sustained Casing Pressure (SCP) back again in March 2017 with similar indication as previous on correlation between tubing pressure and A-Annulus.

This condition been follow-up with another measurement of noise log and temperature had been run in July 2017, but unfortunately cannot determined the leak position. The log was not giving exact leak location

instead of 7 leak possibility on string schematic on figure 3. With this situation the tubing isolation only could recover if the completion was changed-out (both Tubing and Packer).

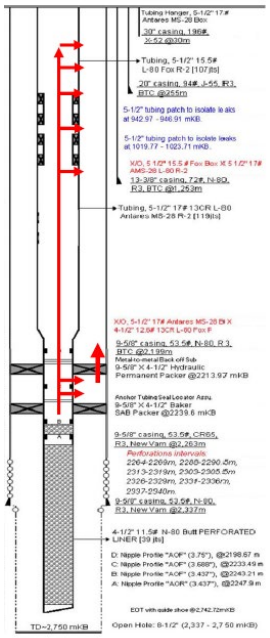


Figure 3. 2nd Noise log (2017) that capture possible leak position from 7 point.

2 Sanggar-06 Well Risk Condition

MEPG developed a comprehensive well assessment with set of parameters to assess the barrier on the wells. The rationale behind developing a fit for purpose assessment tool was the fact that certain parameters are more applicable to mature wells with a lot of production history which gets discounted when compared against new wells. The ideology behind the risk ranking tool honors the fact that "relevant" barrier needs to be used to derive a high/medium/low well risk condition.

While waiting the follow-up program, the Sanggar-06 well continues production after performing well assessment. In the assessment, the Sanggar-06 well has been categorized as medium well condition with current barrier is 9-5/8" production casing with derating component by CO2 (5% content) gas and production casing cement as secondary barrier to contain gas production. To measure the effect of CO2 content to Production casing, one of recommendation is regularly to measure thickness every 2-3 years. The result of thickness reduction will input as derating value to assess well life condition compare with capability of production form this well.

To get low risk well condition the tubing integrity need to established isolation tubing completion as primary barrier from formation gas flow.

3 Noise Log Tools, Technology, Operation & Beamforming Technique Interpretation

3.1 Noise Tool Technology

The acoustic noise log tool has been a popular in recent years for locating the leak source or communication flow when fluid passing through different size of leaks paths, will generate sound with different kind of

frequencies. Historically, majority of these tool have single hydrophone or dual hydrophones with limited operating frequencies, often miss to determine the depth of perceived leak when the downhole environment and well construction structure become more complex. In the recent development, a tool with array of sensor with spacing of 4 inch was created, consist of 8 hydrophones which capable of measuring sound at frequencies from 100 Hz to 100 KHz. These will effectively be allowing for localization of leak events across a 1 meter along-borehole window, thru beamforming the sound waves captured by hydrophone array. Hence more accurate the perceived leak depth can be determined.

3.2 Operation and Beamforming Technique Interpretation

Acoustic noise log tool (ACX) was run on 10th April 2022 to investigate the potential leaks/communication between tubing and A-Annulus under shut-in/static condition (baseline) and stimulated condition (bleed-off pressure in A annulus to lowest possible stabilized pressure). Prior to the ACX run, pressure, temperature survey and electromagnetic thickness detection tool (EPX) run were conducted to understand the temperature gradient profile and any potential interest interval for station pass. EPX run was conducted to investigate the well integrity and corrosion rate profile. The surface pressure measurement for the tubing and all the annuli were monitored throughout the logging period. Any pressure anomalies/pressure drop occurs indicates communication between annulus or pressure stabilization indicates the tubulars are intact, later will provide support evident for noise log interpretation. Amplitude data recorded from each hydrophone during the continuous moving pass in static and stimulated condition, were transformed to Power spectral density (PSD) spectrums using Welch method. Band pass filter was applied on the PSD spectrum to remove road noise generated by tool when moving through the well. PSD spectrum commonly used to provide the first indication of a potential leak by showing distinct amplitude changes signal with frequency as result from the leak's noise. However, the PSD alone, cannot always be used to determine the position of a potential leak because the sound propagation in the wellbore environment is very complex. Figure 4. show the results from acoustic test facility where there was offset between PSD responses and actual leak source position. This is important why beamforming technique is used to obtain the accurate leak point location, even though involve complex multiple annuli. Stationary pass also acquired in static and stimulated condition, to confirm the potential leak from continuous moving pass and beamforming technique also applied to stationary pass to provide accurate radial location.

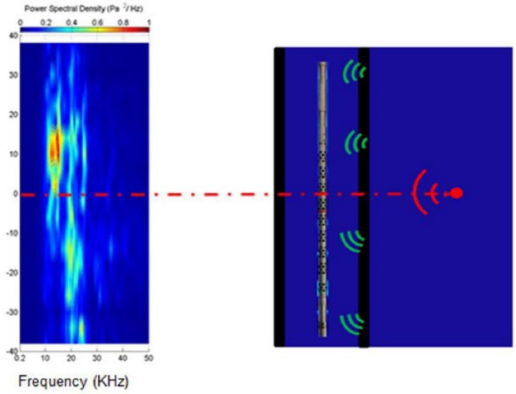


Figure 4. comparison of PSD results and actual leak source position in the acoustic test facility shows the echoes effects on the PSD

The principle of beamforming technique is to use the multiple measurements or waveforms captured by the array of hydrophones to localize the leak in radial distance and vertical depth in the wellbore or surrounding area. An initial model which defines the well construction, velocity, and density of the formation, fluid, casing, and cement were required for the array processing and beamforming is performed, using frequency domain to determine the phase shifts or the delay time of arrivals between hydrophones and create a 2D energy distribution map over the area of interest where the sound source was triangulated. With well construction over the beamforming map, it provides more details about the leak position where the vertical and radial distance of the leak source from middle of hydrophone array.

4 Result Analysis

In Sanggar-06 well, thickness measurement has been carried out in 2017 with electromagnetic metal detection tool as based line thickness and the 1st monitoring measurement was done in 2019. Based on the monitoring results on 2019, there was no significant changes on 9-5/8" casing thickness, therefore the team decided to have another thickness monitoring in 2022.

During 2nd monitoring thickness measurement, Noise log with beamforming technique was added to verify the leak on tubing on Sanggar-06 well. In the beamforming visualization showed on figure 5 suggested that the leak source has position about 2inch vertical and 2inch radial distance from middle of hydrophone array where the station depth at 2210m, there are also more detail description about leak that can be interpreted as the fluid flow in tubing pass thru the leak point and fluid jet disseminating on the outer casing. There is no sign another leak position on string compare to previous noise log on 2017, this result brings another opportunity for the well in order to repair the tubing integrity instead of recompletion program.

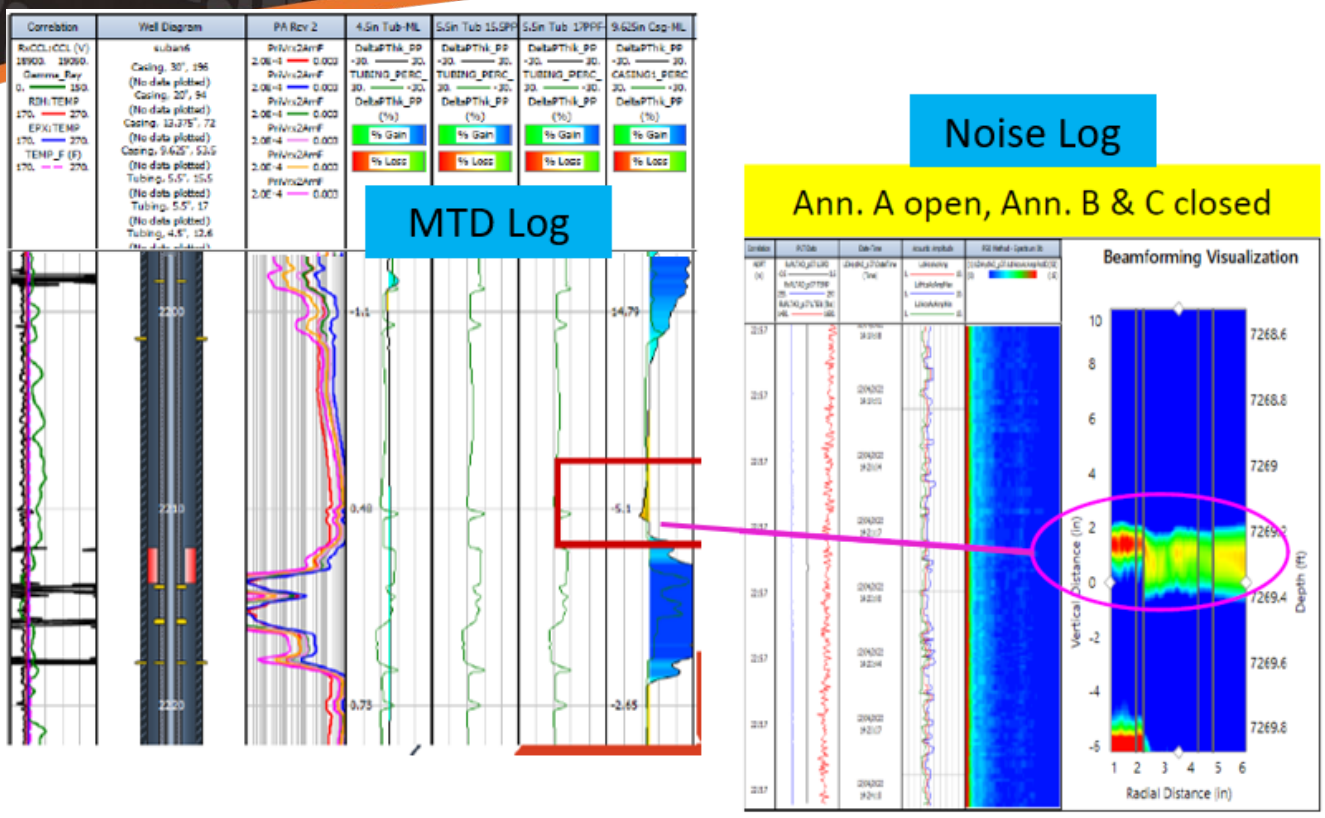


Figure 5. Overlay leak position from noise log with effect on thickness reduction

5 Way Forward and Recommendation Sanggar-06 Integrity Assurance

There are several ways to resolve the tubing integrity on Sanggar-06 with single point leak on Tubing (3 meter above packer).

5.1 Continue Well Production with Periodic Assessment on Casing Thickness

This option exists after evaluation effect on gas production to 9-5/8" casing was low, the significant reduction only behind the leak depth. There is no need budget for repair cost, instead monitoring thickness measurement when the well have prolong production operation for another 3 years. Other mitigation that can be implemented is to close monitor the A-Annulus pressure to manage below Maximum Allowable Well Operating Pressure (MAWOP) and reduce bleed-off operation on A-Annulus to prevent production casing exposed by jetting effect from leak point.

5.2 Minor Repair Activity (cost < $ 500 k)

5.2.1 Spot Activated Resin Thru Annulus

This option exists with implementation Annulus Intervention Service to convey the resin drop to top off packer, the result expected as figure 8 (left). The disadvantage for future operation is that it will need extra work to remove resin and packer if had an optimization plan or future workover.

5.2.2 Installation Straddle Tubing Packer

Installation 3rd straddle packer on 4-1/2" thru previous 5-1/2" double straddle packer at depth 942-946 m & 1019-1023 m will removed capability E-line/slickline tool pass thru the 4-1/2" Straddle packer with ID 1.5". The risk operation also high since the new straddle packer (OD 3.6") need to pass thru ID existing straddle packer (ID 3.9".

5.3 Major Repair Activity (Re-completion, cost >$ 1,500 k)

This is the ultimate activity that can solve tubing integrity, but the cost will 3-5 times higher than minor repair. This becomes last option in regard to production concern, in future it will align with enhancement program or others optimization plan.

5.4 Way Forward Summary

The summary way forward and long-term plans for the Sanggar-06 well integrity to extend the well life can be summarized as below:

- Noise Log with beamforming technique was proven to evaluate small leak condition that lead to certain path forward to mitigate the condition. Without good diagnostic tools or analysis the mitigation may overkill and bring unnecessary spending cost.
- The combination of Noise log and thickness detection give proper assessment in evaluation corrosion due to leaking event on production tubing.
- The Sanggar-06 well continue in production mode after performing risk assessment with manage pressure on A-Annulus under MAWOP.
- No need further investment to mitigate leak issue with well keep stable and manage the risk on ALARP, moreover the leaking issue will be solved when the well has re-completion program in future production optimization.

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